

Final Report

The Test and Evaluation of non-Chromate Finishing Agent

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History

Clark Atlanta University (CAU) is a private, coeducational institution of higher education for students of predominantly African American heritage (a Historically Black College and University, HBCU), formed on July 1, 1988 out of the consolidation of Atlanta University (founded in 1865) and Clark College (founded in 1869) and it is accredited by the Southern Association of Colleges and Schools (SACS). The university, which is situated in the heart of Atlanta, Georgia, offers baccalaureate, graduate and professional degree and non-degree awarding programs to citizens of diverse racial, social and economic backgrounds.

CAU is one of only two private comprehensive HBCUs in the United States of America that awards the doctorate degree in three or more disciplines. It is also a member of the consortium of HBCUs called the Atlanta University Center (AUC). The other members of the consortium include the Interdenominational Theological Center, The Morehouse College of Medicine, and the three colleges : Morehouse (liberal Arts College for men), Morris Brown (coeducational four-year college) and Spelman (a four-year college for women). The Center has a combined enrollment of over 12,500 students and a combined faculty of over 700 at any given period in time since 1988. CAU had a Fall 1999 enrollment of about 5300 students which comprised of approximately 4000 undergraduate and 1300 graduate students with a faculty of about 330.

The AUC consortium affords students many of the opportunities and resources available only at large institutions, while at the same time providing the nurturing environment that is characteristic of moderately sized colleges. The dual degree program provides further opportunities to those students who choose to transition between AUC and the other colleges like GIT, NCA&T, Boston University, Rochester Institute of Technology and Auburn University. Since September 1994 however, CAU has established a baccalaureate

degree program in engineering with options in Mechanical, electrical, civil and chemical disciplines.

It is important to point out that our long-standing relationships with Georgia Institute of Technology, has put us in touch with additional beneficial capabilities/expertise, which is un-surpassed by any measure. We are clearly taking advantage such special relationships particularly as it impacts this effort.

Dr. Cyril Okhio who is an Associate Professor in the **Engineering Department** is the overall Project Manager of this effort. The enormous contributions being made by The **Bi-K Corporation**, Cleveland, Ohio under the leadership of **Dr. Harold Gulley** (collaborating PI) and our very able undergraduate and post-graduate students cannot be over-emphasized.

This effort is pivotal to our objectives to design, develop, and implement a product-related, intelligent testing cell for surface coatings, which focuses on advanced non-chromate materials technology and their commercialization. The cell will also be used to conduct workshop training and research and to demonstrate advanced surface finish testing concepts, processes, and equipment to NASA, industries, manufacturers, students, military development personnel, and small businesses. The accomplishment of this objective requires a systematic approach to designing, installing, testing, and operating the proposed facility.

The Problem

Most military vehicles currently use chromates for corrosion protection on aluminum. The literature shows that chromates are good in salt spray test to a larger extent. Many government agencies are looking for and are willing to try other chromate-free systems that provide equivalent protection. A great deal of data is available for chromates, but not

much is known of other protection systems.

It is well known that chromates provide good protection for aluminum because of their leachability, but with the state of today's laboratory capability, it is difficult to ascertain the current understanding of the pertinent surface chemistry. Besides, there is still a lot of understanding to be gained on the interaction between cleaners, primers and topcoats, and the over-riding oxidation process. Humidity sets the pace!

Aluminum surface protection comes from the leachability of surface and coating chromates. Chromates have the ability to move laterally to protect scratches. According to some scientists, "They are self-healing." This means that when the treated surface is scratched, chromate ions move to cover and protect the "new" bare surface.

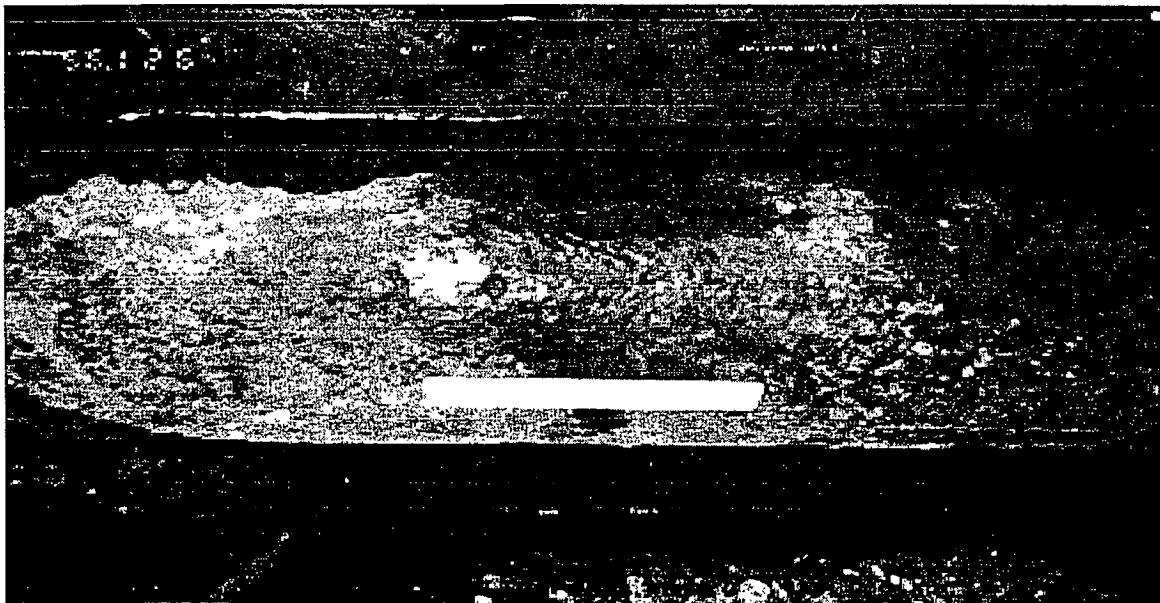


Figure 1. Sample Image of Corrosion In Underground Pipes

Systems Approach to Controlling Corrosion

There are a wide variety of protective coating systems on various military crafts. These are exposed to a wide variety of operating environments. It is well documented that in some situations, chromates perform worse than other compounds. The protection and coating material should be evaluated as a system. From our point of view, the surface effects at each layer are important. They need to be looked at as a “system” from the surface of the structure to the topcoat.

New Protection Systems

Some schools of thought suggest that, it is possible that “designer molecules” could be built to provide custom corrosion protection. Surface modeling might provide a good insight into corrosion, adhesion and other properties of interest to coatings systems; however, this is beyond the scope of this exercise.

In Oregon, a new bridge has a solar cell corrosion protection system. The solar cells provide electrons for movement between aluminum and steel. The Navy protects its ships with 12-foot cathodic rods. Generally, no work has been done for cathodic or sacrificial protection of aircraft bodies.

Test Methods

There is need for a look at current corrosion testing methods such as salt spray and filiform, even though they do not provide a good prediction of the real world environment, neither do they account for acid rain. Also, the tests are comparative and not absolute.

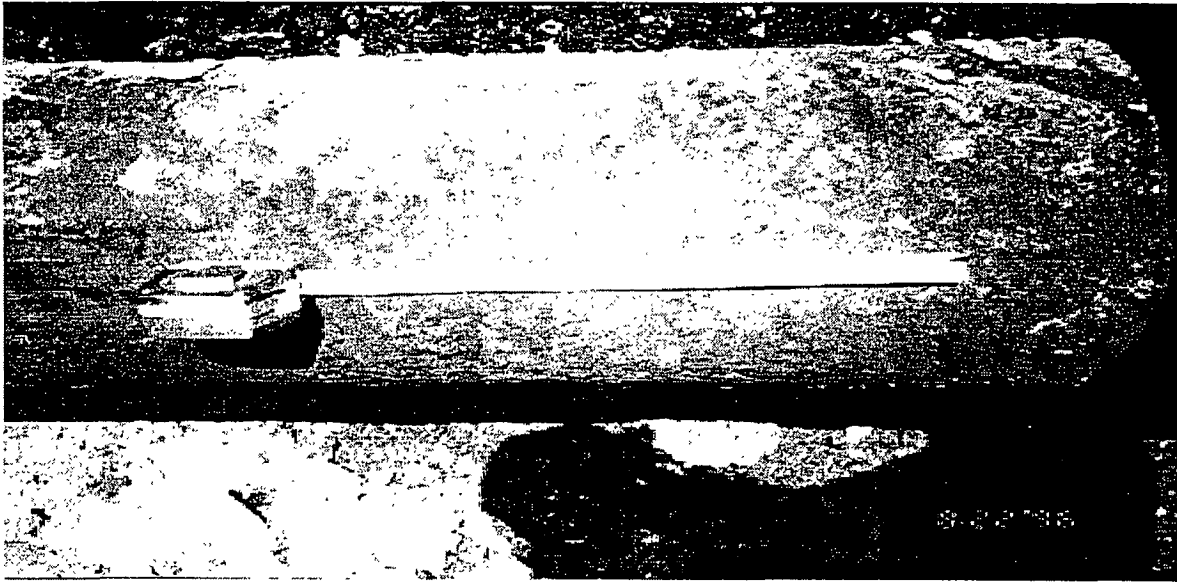


Figure 2. Another Example of Corrosion In Underground Piping System

Current scribe tests have a large degree of variability. Some testers scratch with a razor blade leaving a narrow cut while others result in a .125 to .25 inch gouge. Air Force tests with a standard carbide tool resulted in large variations depending on how the tool was held and who used it. The standard scribe does not exist. Test pass or failure may therefore depend on the scribe.

Better Tests

Not much is known about the physical effects of chromates on the surface of aluminum. Possibly a check on chromate ion content could help develop a model where none exists now. This investigation will reveal that new surface chemistry improvements in the last 5 years could verify what chromates do and provide valuable insight for evaluation and use of other processes.

Vibration Spectroscopy Tests

Vibration spectroscopy, including infrared and Raman spectroscopy, are powerful, non-destructive, techniques that provide information about the chemical functional groups in a sample. In materials and coatings investigations, the most powerful types of investigations using these techniques provide information related to the changes which occur in inter- and intra-molecular bonding interactions as a result of exposure of the material to some reactive gas or coating, a change in the temperature of the material, or an alteration in the processing parameters used to prepare the material. These techniques are commonly used to analyze coating failure modes, and to investigate interfacial interactions between polymer layers, or bonding interactions at a polymer/substrate interface. The current capabilities at CAU include the ability to investigate these interactions on two-dimensional surfaces, with a spatial resolution of approximately 100 μm^2 .

The instrumental capabilities of the vibration spectroscopy laboratory are state-of-the-art, including two Fourier transform infrared instruments, an argon ion (Ar^+) laser Raman spectrometer, and a near infrared Nd^+ -YAG Fourier transform Raman spectrometer. One of the infrared instruments and the Ar^+ Raman spectrometer have associated microscopes and two-dimensional mapping software that provide functional group surface mapping capabilities, with 100 μm^2 spatial resolution.

Salt Spray Tests

The salt spray test was devised over 35 years ago. It was proposed as an equivalent of a seacoast or marine atmosphere for the study of protective metallic coatings on iron and steel in 1914 by J.A. Capp in an article published in *ASTM*, Vol. 14, p. 474, entitled “A Rational Test for Metallic Protective Coatings”. Circular No. 80 of the National Bureau of Standards, published in 1919, on “Protective Metallic Coatings for the Rust-Proofing of Iron and Steel”, expounded the value of the salt spray test. Possibly due to the lack of any other standardized form of test, the salt spray test was written into numerous specifications. Immediately, the test became the subject of adverse criticism. During the 1920's, *ASTM* Committee B-3 undertook a study of the salt spray test along with studies of the numerous other methods of accelerated corrosion testing. Many organizations cooperated in this work of Committee B-3. Large quantities of data indicating the limitations of the test were published, and are valuable to this effort.

Until the early 1930's it was usual practice to operate the salt spray test at ordinary room temperature. About that time, the National Bureau of Standards installed a salt spray chamber in a temperature-controlled room that was being maintained for some other purposes at a temperature of 95 *F*. Naturally, it was found that corrosion proceeded more rapidly at this slightly elevated temperature than at room temperature. This increase in temperature accelerated the rate of testing and this acceleration was claimed to be desirable. About 1936, some of the government agencies changed their requirements in connection with salt spray corrosion testing to conform to this higher temperature. This

change resulted in still more exploratory work being done by the various bodies cooperating with ASTM Committee B-3.

Problem Design Accomplishments

CAU has engaged a team comprised of university faculty members, student research assistants, and consultants from industrial and technology firms in order to ensure that NASA receives a quality product on time and within budget. In addition to the current related expertise which CAU possess, we have enlisted materials and aid from several other agencies, and machine manufacturers to assist us in completing the project on time and according to plan and budget.

The research team is employing sound engineering principles in its approach to this project. Each phase of the project is preceded by a thorough and complete planning session that details the work plan and provide a comprehensive review of the work to be accomplished during the particular phase and by whom. Maximum use is being made of existing or already planned capabilities to ensure maximum economy, and frequent on-line reviews are being held to measure progress and to identify potential problem in sufficient time to allow for corrective action.

Upon the award, a kickoff meeting was held to finalize the implementation strategy and to coordinate the responsibilities between CAU, and our industrial consultants. The phase I work plan was developed and coordinated among the various representatives and

student research assistants, and individual tasks were assigned.

An in-depth study of the cell requirements has been carried out. Emphasis was placed on determining the capabilities of existing equipment/software, the needs for additional equipment/software, the requirements for the SINGLETON Cyclic Corrosion Chamber machine, and the physical location and arrangement of the equipment within the cell.

Components to be integrated into the cell during this phase are still being examined to determine their compatibility and requirements. This will be accomplished through a review of equipment/software specification and a discussion of equipment/software capabilities with Bi-K Corporation and Singleton Corporation. Based on the results of the analysis completed in task 1 above, new materials/equipment/software needs have been identified. Candidate items are being examined to determine which items best meet our needs. As a result of this examination, the most suitable hardware/software systems have been selected and procured/ordered.

A physical layout design of the test facility has been developed. The layout was determined after a thorough evaluation of the existing facility and infrastructure (**SRC-B29**) against the equipment requirements determined above. Key considerations in the physical layout are the capability for growth for future phases and the projected usage of the facility for both CAU, NASA and the US industries.

Wherever possible, all acquisitions of new equipment/software have included

installation/training as part of the purchase. Qualified CAU personnel, with licensing rights and assistance from industrial consultants, oversee installations to ensure that the equipment is properly installed and tested before acceptance.

Necessary site surveys have been carried out prior to any hardware/software installation, to ensure that facilities are adequate to accept the items to be installed. Special attention is paid to the power supply/supply phase and weight requirements of the equipment. Actual installations will be accomplished by company representatives from the software/equipment provider by May 1, 2000. CAU personnel will assist where necessary.

We have completed all the Tasks of making the cell operational by thoroughly testing each of the individual parts and the system as a whole.

Each individual cell component was tested to ensure proper operation. This procedure verified the operational status of the cell and provided information used to make any necessary modifications to the cell or any of its components.

Industry Practices Reviewed Thus Far

Allied Corrosion Industries 1998 Basic Corrosion Premise

a) Dissimilar Metal Corrosion Cells (Galvanic corrosion)

Two metals of different compositions are metallurgically contacting each other in a common electrolyte. The magnitude of potential difference between the two metals

will determine which metal will be the cathode.

b) Dissimilar Electrolyte Corrosion Cells

This type occurs when a structure passes through an electrolyte of varying properties.

c) Differential Aeration Corrosion Cells

Where part of a structure is in soil having a free supply of oxygen and an adjacent area is in oxygen-starved soil, the part of the structure in the well-aerated soil will be the cathode and the part of the structure in the poorly aerated soil will be the anode.

d) New Structure/ Old Structure Corrosion Cell

In this phase there is an electrical potential between two metals in a common electrolyte. Unfortunately this type of corrosion the newer structure will normally become the anode.

Defense Science and Technology Organization. - Bruce R.W. Hinton. September 1991.

Corrosion Prevention and Chromates, the End of an Era?

Chromates have been one of the most widely used chemicals in the metal finishing industry. Although chromates also are toxic and carcinogenic but are excellent corrosion inhibitor. In chromate, the mixed chromium/substrate metal oxide coating provides better corrosion resistance than the substrate metal oxide alone. Another property of the chromate coating is its ability to improve the adhesion of paint coatings. Some side

affects of chromate are the cause of kidney failure, liver damage, blood disorders and eventually death.

Products Finishing, May 1996.

Water-Borne Coating Improves Air Quality

Water-borne coatings have to resist damage from chemicals and other lubricant's stored in containers. Raw materials that are needed to produce water-borne coatings are more expensive but is more cost-effective in the end. Water-borne coatings often have a faded and dull look to it and does not adhere to cold-rolled steel as well as solvent-borne coatings.

Military Plating Specifications. August 1996.

Black Chrome

A hard, non-reflective, abrasion-resistant, heat and corrosion resistant coating and provides limited corrosion protection.

Black Oxide Coating

Mostly a decorative coating, only very limited corrosion protection under mild corrosion conditions.

Chrome

Excellent hardness, wear resistance, and erosion resistance and is resistant to heat.

Copper

Copper in color and matte to a very shiny finish. Good corrosion resistance when used as an undercoat.

Phosphate Coating; Heavy

A coating for medium and low alloy steels, gray to black in color and is intended as a base for holding/ retaining supplemental coatings which provide the major portion of the corrosion resistance.

Magnesium Finishing Processes. Algal Kibbutz Alonim. February 16, 2000

Non Chromate conversion Conducting coating:

12 hours in salt spray test, good paint adhesion, no change in measures and in fatigue strength.

Non Chromate Conversion Coating:

16 hours in salt spray test, 500-600v breakdown voltage, high porosity. Excellent paint adhesion

Sealed Non Chromate Conversion Coating:

48 hours in salt spray test, 500-600v breakdown voltage, high operating temp., resistance to milled acids and bases.

Raychem Corporation 1996-1998

Corrosion Protection and Sealing

To protect metal pipe structures in contact coatings must have a high electrical resistance, and low permeability to hydrogen and oxygen. Must also be chemically stable.

Pollatum 1997

A Petrolatum based corrosion protection tape

Pollatum tape system s highly compatible cold-applied pipe wrap, comprised of a synthetic fibre carrier and coating with an inert petrolatum. Tape will not harden or crack and is impermeable to water and very resistant to mineral acids, alkali and salts.

Corrosion Inhibitor Products

Corrosion Inhibitor's CI Vapor Tablets

These tablets are composed of a chemical compound that when exposed to air will produce a volatile corrosion inhibiting vapor. It also prevents corrosion on metals chrome plates and other non-metal surfaces. It will protect from 3 months to 10 years.

Australasian Corrosion Association, March 16, 2000.

The Corrosion Process

Corrosion can be defined as the destruction or deterioration of a metal or non-metal material from the result of the surrounding environment. Micrometers are the metric expression for uniform corrosion. The expressions are calculated from weight-loss data using the following equations:

$$Mm = 87.6W$$

There are four essential constituents of a corrosion cell: Anode, Cathode, Electrolyte and Conducting link. The anode is where the metal is corroded and electrons are produced. The cathode gets rid of the electrons produced by the anode which in part reacts with oxygen and water molecules to form negatively charged particles known as hydroxyl ions. The electrolyte contains positively and negatively charged ions and conducts electricity. The positively charged ion from the corroding anode follows into the electrolyte. Then at the cathode, positively charged ions are neutral species take up the electrons flowing in the electrical circuit. The flow of ions in the electrolyte completes the electrical circuit. Last is the conducting link where the electrons have a means to travel from the anode to the cathode.

Corrosion is the electrochemical degradation of metals or alloys due to reaction with their environment: the chemical reaction that occurs between a metal and its environment that leads to the destruction of any material by chemical agents and electrochemical reactions. Atmospheric corrosion occurs when the oxygen of the atmosphere reacts with the surface of a metal known as rusting. Another type of corrosion is Galvanic or two-metal corrosion. This similar cell type of corrosion occurs when two different metals in contact set-up an electrical potential between them and are surrounded by an electrolyte, producing a closed circuit.

The equations listed are electrochemical reactions found in corrosive metals and show that oxygen and hydrogen play an important role in metal corrosion:

Anodic reaction: $M^0 \rightarrow M^{++} + 2 \text{ electrons}$

At the cathode: (1) $2H^+ + 2 \text{ electrons} \rightarrow H_2\text{gas}$

(2) $\frac{1}{2} O_2 + 2H^+ + 2 \text{ electrons} \rightarrow H_2O$

(3) $O_2 + 2H_2O + 2 \text{ electrons} \rightarrow H_2O_2 + 2OH^-$

(4) $\frac{1}{2} O_2 + H_2O + 2 \text{ electrons} \rightarrow 2(OH)^-$

Although the overall corrosive process is shaped from the environment in which a metal is placed, there are certain corrosive agents that contribute to the degradation of the metal. The combination of oxygen with a thin film of liquid that is adjacent to the metals surface and then transported through the same film can create an electrochemical corrosive reaction along with air pollutants such as the ozone, nitrogen oxides, nitric acid and organic peroxide.

The checking and maintenance of corrosion on metals can be performed by using different instruments. The design of corrosion monitors is among the most recent development in corrosion detection, along with hydrogen test probes and infrared thermographic techniques. Resistance testing of metal corrosion can be performed by using different salt spray or condensing type chambers. Although we monitored the corrosion of the metals manually, the Singleton Salt Spray chamber was used to perform the testing.

After setting up the Singleton Salt Spray chamber a series of test were ran on unpolished aluminum coupons that were sent to us by the ACT Laboratories. Although there were

different methods of testing the coupons, each test was performed to observe and possible prevent the spontaneous destructive oxidation of metals. The average run of testing was between sixteen and twenty hours. Before the coupons were placed in the chamber they were placed in a degreaser followed by a methanol rinse and either coated with lemon juice, mild detergent, distilled water, Hibiscus or Green tea and then weighed. Before we tested the coupons we researched previous testing on Corrosion prevention done by other companies to gather information and construct our own testing methods.

Touchstone Research Laboratory, Corrosion Potential Testing (ASTM G69)

Samples were exposed to a salt water/peroxide medium along with a saturated calomel electrode. The corrosion potential data, in mill volts, was collected by using a PC and used to plot a corrosion potential curve. To better improve the method of layer removal on the metals surface, the Touchstone research team developed an electrochemical machining technique for layer removal in minutes in a predictable manner. Using a DC power source and a copper counter-electrode, the test specimen is suspended in a salt solution while current is passed through the system to remove metal in discrete amounts. The sample can then be re-introduced into the test cell and the test continued.

Morrison, J.D., Study of Corrosion Protection Methods for GSE Applications at Kennedy Space Center, 5/72.

This is a status report covering the work accomplished from 2/70 to 4/72 on a program,

conducted for the Mechanical Design Division by the Materials Testing Branch, to evaluate corrosion control and treatment methods for Ground Support Equipment at KSC. The purpose of the program was to evaluate the procedures recommended in the manual, using actual hardware items with the relevant treatments applied. Samples of stainless steel, aluminum, carbon steel, and galvanized steel parts were obtained and treated with various corrosion-preventative materials, such as chemical conversion coatings, paint systems, vapor-phase corrosion inhibitors, fluidized-bed coatings, tapes, solvent-cutback compounds, and greases. Duplicate sets of all specimens were prepared and placed at the KSC Corrosion Test Site, one set being placed in an exposed location and the other in a sheltered location.

Conclusions reached after two years of exposure testing are as follows:

- For aluminum alloys, a three-coat paint system and inorganic zinc paint have given complete protection. A chemical conversion coating (MIL-C-5541) was useful for short-term protection.
- For stainless steels, sacrificial type coatings (such as zinc-rich and aluminum rich paints), polyethylene tape, and a fluidized-bed epoxy coating, gave excellent protection. A solvent cutback material, MIL-C-16173, Grade 2, was satisfactory for short-term protection.
- For galvanized steel parts.
- For carbon steels, a vapor-phase corrosion-inhibiting compound (MIL-L-46002) protected internal surfaces of enclosures subject to moisture intrusion. None of the treatments applied to external surfaces, directly exposed to the seacoast environment, gave adequate long-term protection, although some of the MIL-C-16173 compounds were useful for short-term exposures.

Dr. Wessling Bernhard, Scientific Engineering of Anti-Corrosion Coating Systems based on Organic Metals (Polyaniline),

The new corrosion protection technology with polyaniline, the Organic Metal (conductive polymer) is presented. It is based on an immense surface ennobling and the formation of an aestivating metal oxided. The requirements for efficiently working coating systems, comprising the dispersed Organic Metal containing primer, eventually an intercoat, and an op coat, are characterized. Organic Metal Coating systems are out-performing even the best conventional anti-corrosion coating systems. In 1986 they began research directed to polyaniline containing anticorrosion coatings and realized the first dispersion coatings in 1987. After 5 years of intensive research, they discovered tow new phenomena enabling us to provide excellent corrosion protection:

- *Ennobling (a strong surface corrosion potential shift)*
- *Active passivation (the formation of a passivating metal oxide layer, in the case of iron stoichiometrically composed of Fe_2O_3).*

They were also revealed that the Organic Metal was providing corrosion protection

- a) *by being a noble metal*
- b) *by being a catalyst*

Morrison, J.D., Corrosion Study of Bare and Coated Stainless Steel, 2/71.

Need for the program conducted for the Mechanical Design Division by the Materials Branch, to evaluate the performance of austenitic stainless steel was dictated by the occurrence of numerous failures of stainless steel hardware, caused by pitting and stress-corrosion cracking, over the past several years. Test have been conducted to determine the inherent corrosion susceptibility of several alloys and to evaluate the effectiveness of

certain sacrificial-type protective coatings in preventing corrosion failures. Samples were placed in racks approximately 100 yards above high tide line at Cape Kennedy. The racks were designed to provide complete exposure of half of each tubing sample and shelter from direct rain impingements of the other half. Protective coatings and treatments evaluated include organic- and inorganic- zinc-rich paints, an aluminum filled proprietary coating, and periodic surface treatment with a phosphoric acid wash.

- All of the unprotected tubing samples showed evidence of pitting initiation after about two-week exposure at the beach test site.*
- The deepest pitting generally occurred in the sheltered portion of the tubing samples, probably because of the retention of deposits from salt fogs.*
- Zinc-rich coatings, both inorganic-base and organic-base, and an aluminum filled coating, have afforded sacrificial protection to the stainless steels against pitting, for as long as 28 months, and against stress-corrosion cracking of fittings, for as long as 12 months.*

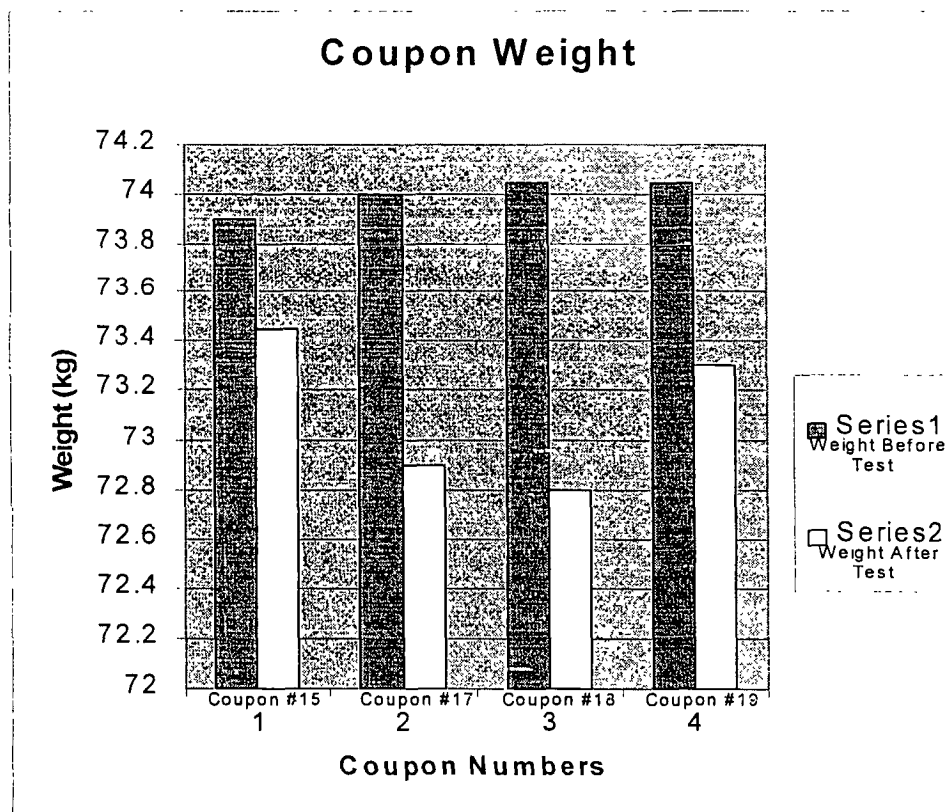
We also studied the Cosmetic Corrosion Lab Test done by the Engineering Society for Advancing Mobility for reference. This particular test is performed to determine cosmetic corrosion performance for coating systems, substrates, processes, or designs. Similar methods from the *cosmetic lab test* such as cleaning coupons and spacing of coupons on the rack were used in our testing procedures.

** Corrosion coupons shall be thoroughly cleaned to remove all forming and storage oils with a commercially available degreaser followed by a methanol rinse. Then the mass in milligrams shall be recorded and retained for future reference. [We used dish washing liquid to degrease the coupons before testing, followed by the hydrochloric acid, water, and hexamethylene tetra mine rinse to*

clean the tested coupons after which the mass loss was determined]

** Allow a minimum 5 mm spacing between the coupons and the rack surface.*

After testing, the coupons were then cleaned and rinsed with a combination of Hydrochloric acid, distilled water and hexamethylene tetra mine and then weighted again to find the mass loss (Initial mass – Final mass). Although we did not calculate the corrosion rate, it can be determined by measuring the electrical current flow between the test and auxiliary electrodes, after which the current is measured on a micro ammeter that has been converted into mils (1 mil = 0.001 inch = 25.4 micrometers) per year of the test electrode.



APPLICATION OF CORROSION-RESISTANT METALS

Metal	Corrosion Resistance Use	Consumption	
		For corrosion Applications	Percent of All Uses of Metal
Aluminum	Alloying; coatings; cladding	225,000 metric ton	5
Chromium	Alloying, 57%; coatings and plating, 7%	306,000 metric ton	64
Tin	Plating, tinning	19,800 metric ton	34
Manganese	Alloying; cladding	45,000 metric ton	4
Magnesium	Alloying; sacrificial anodes	14,400 metric ton	15
Copper	Alloying and plumbing	370,000 metric ton	18

SOURCE: U.S. Bureau of Mines

There were a number of defaults and complications that were confronted during the testing process. Throughout and after testing, a number of coupons showed common corrosion patterns of rusting, pitting, layered flaking of rust before cleaning and black oxidation or fungus which were caused by either poor handling of the coupons, improper cleaning or over exposure of oxygen after rinsing. (Other forms of corrosion are stress corrosion, corrosion fatigue, inter-granular corrosion, corrosion-corrosion and uniform attack or general wastage). Consequently we began using rubber gloves and tongs to handle the coupons before and after testing and made sure to rinse the

coupons under a hood to prevent over exposure. After these precautions were taken, we still were having problems with failed coupons so Harold Gulley, the founder of Bi-K Corporation , Cleveland, Ohio, sent us some coated coupons that were to be tested in the chamber and then analyzed and compared. After testing his coupons in the chamber, we began to see a vast change from Harold's coated coupons and our cleaned coupons. It seemed that his coating was what made the difference!!!

Conclusion

The experimental strategy and procedure have been carefully undertaken and it appears that they have helped us in carrying out the project design objectives. By the end of the first phase, we were at an advanced stage of clarifying the needed understanding that underlies Corrosion protection using Chromate and any of its other environmentally responsible replacements, particularly the Bi-K Process. We are now able to clarify the problems associated with the important issues of surface preparation prior to surface finishing in the materials industry.

A good number of minority students who worked on this effort have been exposed to various aspects of the materials industry and more importantly to the intricacies of inventions, their development and commercialization. They also got a good look at NASA as an employment option.

The Bi-K alternative for corrosion protection demonstrated that its effectiveness under the Salt Spray B117 Tests that we carried out here at CAU. Its advantages as a non-toxic, water-based alternative to Chromium worthy of further investigation and adoption by the

Metal and non-metal Coating industry and we strongly recommend that.

Thank you NASA, once again, for the opportunity.